Understanding Spatial Orientation of VR Users in the Physical Environment

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ABSTRACT

Spatial orientation and spatial memory are essential abilities that allow directing and moving inside an environment. Virtual Reality (VR) users are disconnected from the real world for higher immersion and presence. The discrepancy between the physical and virtual environments may cause accidents (e.g., collisions), eliciting concerns about the safety concerns of VR users. In this submission, we investigate the VR user's spatial orientation in the physical environment, exploring factors that disturb or decrease spatial orientation during a VR experience. The goal is to understand how much spatial orientation in the physical environment can a VR user preserve, considering different levels of presence in VR and different reference frames. Results can suggest the trade-off between having a high level of presence and being aware of the physical environment to enhance future VR safety mechanisms.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **Empirical studies in HCI**.

KEYWORDS

spatial orientation, spatial memory, presence, VR safety

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1 INTRODUCTION

Imagine that you are in an immersive Virtual Reality (VR) experience. While walking towards a target, you notice it is outside of the VR safety boundary (e.g., Oculus Guardian[1]), but you roughly know that is where the coffee table locates in your living room. Thus you break out of the VR boundary and reach the target because you are sure that there is plenty of space above the coffee table. During this scenario, VR user has to orient themselves in (1) the virtual and (2) physical environment simultaneously. *Spatial orientation* — the ability to identify the position or direction of objects or points in space [1] — allows us to perform the task described above.

VR user has to decide their movement based on their spatial orientation in both environments, but they are temporarily disconnected from the physical environment because of wearing a Head-Mounted Display (HMD). In this case, they rely not only on the notification cue from VR safety boundaries but also recall what is there in the physical environment, planning how to interact. This process is associated with *spatial memory* — storage and retrieval of information that is needed both to plan a route to the desired location and to remember where an object is located or where an event occurred [3, 19].

Recent research explores different modalities to enhance the efficiency of VR safety boundaries [8, 9]. However, although VR safety boundaries exist, accidents (e.g., VR fails [7]) still happen in everyday VR usage. Perceptual manipulation techniques in VR have the potential of provoking physical harm to users in the future by malicious actors [22]. The safety of VR users becomes a concern. There is a lack of understanding about the trade-off between being fully immersed and aware of the physical environment.

In this submission, we introduce a research direction studying the VR user's spatial orientation in the physical environment and presence in the virtual environment and what factors may disturb spatial orientation while navigating in VR. Participants enter a controlled environment surrounded by several physical objects. They have to perform a navigation task in VR followed by a pointing task. It asks participants to point toward the object inside the physical world and indicate their position in the space by recalling it. We hypothesize higher presence in VR competes with the user's resources for processing spatial knowledge, resulting in lower task performance of spatial orientation. We are also interested in presenting different reference frames (e.g., landmark, safety boundary) for enhancing spatial memory. Finally, the study allows us to observe the learning effect of participants' spatial orientation in the physical environment.

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[1]https://developer.oculus.com/documentation/native/pc/dg-guardian-system/

The expected contributions would suggest the trade-off between having a high presence and being aware of the physical environment. An example would be how to inform the VR user with different reference frames for the future VR safety mechanism.

2 BACKGROUND AND RELATED WORK

This work is related to spatial orientation and spatial memory. We review research around presence and VR safety.

2.1 Spatial Orientation and Spatial Memory

Spatial orientation is an essential skill for the everyday task of humans, identifying the position or direction of objects or points in space [1]. Previous VR research associated spatial orientation with locomotion techniques in an immersive virtual environment. The idea was to improve the performance of navigation [2, 13] and reduce the inconsistency in spatial updating process [11]. Most of the previous works focus on spatial orientation in the virtual environment. As VR moves towards mobile, preserving spatial orientation in the uncontrolled physical environment becomes relevant because a VR user might want to preserve the awareness of reality while interacting in an unknown space.

Because VR users are disconnected from the physical environment, commercial VR products use safety boundaries to notify the limit of an interaction space. When VR users interact inside a physical environment, they also rely on spatial memory — storage and retrieval of the spatial information [3, 19] — to orient themselves in space. Human-Computer Interaction (HCI) researchers studied how spatial memory can enhance task performance in a various of interfaces (e.g., virtual environment [6], wall display [10], and graphical user interface [18]). Spatial memory can be divided into egocentric (i.e., centered on the user) and allocentric (i.e., centered at an external point in the environment) spatial memory [12, 24]. To inform spatial orientation in the physical environment, one can consider designing a *reference frame* in VR that represents spatial knowledge, enabling a person to maintain and update their awareness of position and direction when traveling through an environment [14]. This work seeks to explore the effect of different reference frames on the spatial orientation in the physical environment.

2.2 Presence vs. Safety in VR

VR devices provide multi-sensory input (e.g., visual, audio, or haptic) and motion tracking to enable an immersive experience. The hallmark of a VR experience is usually interpreted by the sense of presence [21]. Presence is a psychological state in which a user feels "being there" inside a computer-mediated environment [25]. Ruddle and colleagues [16, 17] showed using the walking interface in a virtual environment has benefits for navigation. Using walking as a locomotion technique also improves presence [23]. Research in HCI strives for enabling unlimited walking experience for the future mobile VR [5, 26].

Recent research started to discuss the implication of the realism of VR technologies [20]. Because a user is dominated by the information in VR, one can hack the software [4] or the human perception [22] to provoke harmful impact, creating safety and security concerns. Many accidents (e.g., VR fails [7]) are already happening in everyday VR usage. Exploring the effect between presence in VR and spatial orientation in the physical environment can help us understand VR users' behavior. This exploration can suggest a trade-off between being fully immersed and having a certain amount of awareness of the real world for enhancing future VR safety mechanisms.

3 RESEARCH PLAN

In this section, we propose a tentative plan for studying spatial orientation in the physical environment of VR users. We plan to examine the following hypotheses to understand the factors disturbing spatial orientation in the physical environment while using VR.

> **H1:** A higher presence in VR disturbs more spatial orientation in the physical environment (e.g., reduce task performance, increase completion time).

Executing the task in VR and maintaining the spatial orientation in the physical environment is a dual-task process. Because VR users have limited cognitive resources for both tasks, we expect to observe higher presence would decrease spatial orientation in the physical environment. The idea would be to induce a different level of presence and correlate it with the measures of spatial orientation.

> **H2:** Using *landmark* as a reference frame has a better performance in spatial orientation compared with notifying the interaction space (*safety boundary*).

H2 aims to enhance the VR user's spatial memory with different reference frames (*landmark*, *safety boundary*, and *none*). We expect with *landmark* VR user can have a better task performance of spatial orientation because landmark contains more spatial knowledge compared to *safety boundary*.

3.1 Design

The study has to induce different levels of presence, which can be achieved by the fidelity of VR content and virtual body ownership. Two independent variables are Virtual Realism (*abstract* and *realistic*) and Virtual Body (*full body* and *none*). These variables are within-subject variables so that we can induce different levels of presence in one participant.

Besides presence, we are interested in another independent variable, Reference Frame, that contains *safety boundary*, *landmark*, and *none* to inform spatial memory of VR users. The *safety boundary* indicates the walking area of a physical space. The *landmark* shows the silhouette of objects in the physical environment. The experiment would be a mixed-design with one between-subject variable (Reference Frame) and two within-subject variables (Virtual Realism and Virtual Body).

3.2 Environment Setup and Apparatus

The study would be carried out in a controlled lab environment. Several objects (e.g., sofa, cabinet, and door) are also a part of the experiment because they are targets for the pointing task. Participants wear Oculus Quest 2 to avoid the constraint of cables. We choose real walking as the locomotion technique to navigate inside VR with a higher presence.

3.3 Task and Stimuli

Figure 1 shows the process of the study. First, participants enter the room, and they see the physical environment. Next, they put on the HMD and receive the instruction inside VR. They have to do a

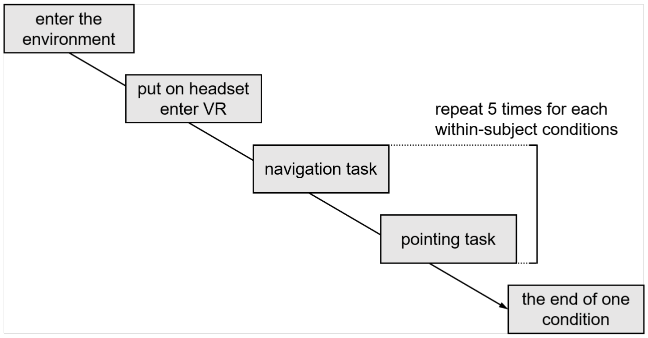

Figure 1: The process of the experiment

navigation task — traversing in VR and searching hidden targets in 16 boxes with walking [14, 15]. Only eight boxes contain the target. The goal of the navigation task is to collect all the targets as fast as possible. After finishing the navigation task, we disable the reference frames, and the pointing task starts. Participant has to point toward the location of an object inside the physical environment (assigned by the user study application) with the controller (e.g., raycasting). They also have to indicate where they are in the physical space on a 2D panel in VR. The navigation and pointing task repeats five times for each condition. At the end of each condition, participants have to fill out a presence questionnaire in VR.

Reference Frame Design. All the REFERENCE FRAME designs are referred to the VR safety boundary (e.g., Oculus Guardian). They indicate the physical environment while participants are approximating it. The *safety boundary* is a replication of Oculus Guardian, which only shows the walking limit of the space. The *landmark* shows the silhouette of objects inside the space. In the pointing task, all the reference frames are disabled.

3.4 Measures

In the navigation task, we measure the traverse path, completion time, the number of revisits, and the number of targets found before the 1st revisit. These metrics are the measurement for spatial orientation inside VR. In the pointing task, we record the angle offset of the raycasting by participants and the direction between the assigned object and the participant. We also measure the distance between the participant's actual position and the indicated position by themselves. Presence and virtual body ownership are measured with the single-item response (1-10 Likert scale). At the end of one condition, participants fill out a presence questionnaire (e.g., SUS).

3.5 Discussion

In the workshop, we want to initiate a discussion about understanding the user's spatial orientation in the physical environment while navigating in VR. We want to discuss the experiment design, and whether the tasks are relevant, what could be other measurements for spatial orientation and presence. We expect to polish our hypotheses and study design.

4 CONCLUSION

In this statement, we introduce a research direction of studying which factor may disturb spatial orientation in the physical environment using VR. Several factors (e.g., presence, reference frames) are proposed inside the research plan. We are also interested in observing the spatial learning effect of the task. The expected results can inform the trade-off between presence in VR and awareness in the real world, enhancing future VR safety mechanisms.

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